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During the grant period we have carried out work on various aspects of plasma physics. These include theoretical studies of equilibrium and non-equilibrium properties of strongly coupled particle systems, and of the phenomena which take place when neutral or partially ionized atoms interact strongly with external fields and with each other in a plasma. The main tools of our study are statistical mechanics and kinetic theory, including the transition from a microscopic to a hydrodynamic description. Quantum mechanics plays a central role in many of these problems, and is an important ingredient in our work.

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TECHNICAL REPORT

AFOSR GRANT 92–J–0115

BASIC STUDIES IN PLASMA PHYSICS

February 1, 1992 — January 31, 1995

by

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Introduction

During the grant period we have carried out work on various aspects of plasma physics. These include theoretical studies of equilibrium and non-equilibrium properties of strongly coupled particle systems, and of the phenomena which take place when neutral or partially ionized atoms interact strongly with external fields and with each other in a plasma. The main tools of our study are statistical mechanics and kinetic theory, including the transition from a microscopic to a hydrodynamic description. Quantum mechanics plays a central role in many of these problems, and is an important ingredient in our work.

1. ELECTRON VELOCITY DISTRIBUTION IN A WEAKLY IONIZED PLASMA WITH AN EXTERNAL ELECTRIC FIELD

The velocity distribution $f(v)$ of the electron component of a weakly ionized plasma is investigated in a spatially homogeneous external electric field E. Both static and time-dependent E are considered. The time evolution of f is described by a Boltzmann equation in which the ions and neutral particles are assumed to have a Maxwellian distribution with *a priori* specified temperatures while the electron-electron interactions are given by a Landau-type collision integral. The (approximate) solution scheme used to solve this equation for a stationary f (in a constant field) is found to have nonunique solutions for certain ranges of E, in agreement with that found in earlier investigations using a different method of solution. These results are interpreted to correspond to hysteresis effects when the field is changing very slowly: with the true stable solution undergoing a very sharp changeover, possibly a discontinuous transition, at a certain critical E. This can be understood intuitively as a transition in the stationary state of the electrons from a low-energy regime dominated by strong coupling to the ions to a high-energy regime dominated by electron-electron and electron-neutral collisions.

2. NONLINEAR RESPONSE OF A DISSIPATIVE BLOCH PARTICLE IN AN OSCILLATING FIELD

We study the Caldeira-Leggett model of a particle coupled to a heat bath moving in a periodic cosine potential. In the limit of small viscosity we obtain an integral equation for the nonlinear response of the system to a constant or a slowly oscillating field. The equation is derived by a resummation of the infinite series expansion in the strength of the cosine potential. When solved via a self-consistent approximation it gives an *analytic* expression for the response function. Applications to Josephson junctions driven by a low-frequency source are discussed.

3. ATOMIC VERSUS IONIZED STATES IN MANY-PARTICLE SYSTEMS AND THE SPECTRA OF REDUCED DENSITY MATRICES: A MODEL STUDY

We study the spectrum of appropriate reduced density matrices for a model consisting of one quantum particle ("electron") in a classical fluid (of "protons") at thermal equilibrium. The quantum and classical particles interact by a short-range, attractive potential such that the quantum particle can form "atomic" bound states with a single classical particle. We consider two models for the classical component: an ideal gas and the "cell model of a fluid". We find that when the system is at low density the spectrum of the "electron proton" pair density matrix has, in addition to a continuous part, a discrete part that is associated with "atomic" bound states. In the high-density limit the discrete eigenvalues disappear in the case of the cell model, indicating the existence of pressure ionization or a Mott effect according to a general criterion for characterizing bound and ionized electron proton pairs in a plasma proposed recently by M. Girardeau. For the ideal gas model, on the other hand, eigenvalues remain even at high density.

LIST OF PUBLICATIONS
SUPPORTED BY AFOSR GRANT

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